Components in wireless technology, 5XTC0

Module 4
Lecture: RF systems

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Where innovation starts

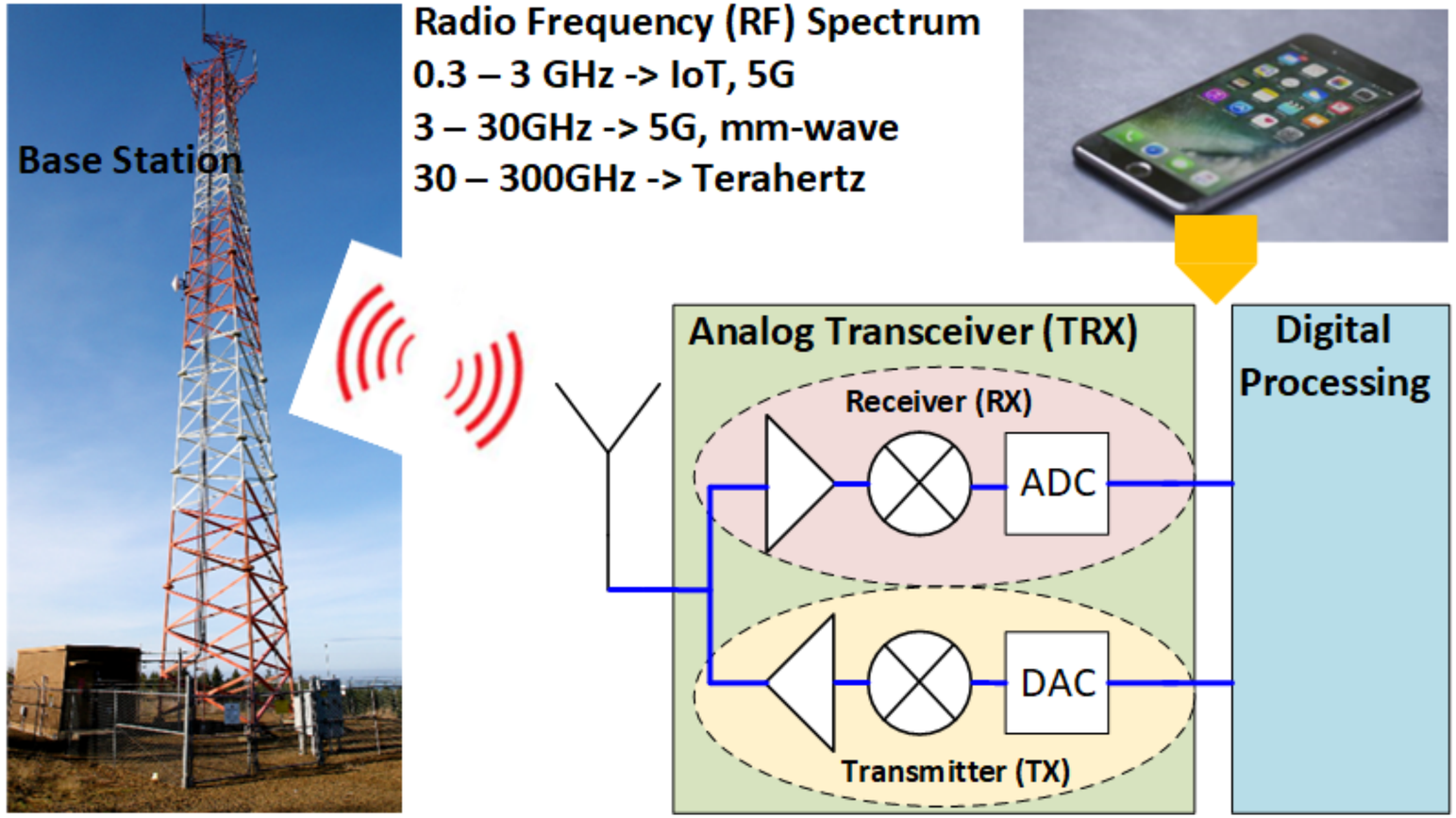
Outline

- Goals of the lecture
- Scope
- Trends & challenges in wireless communications
- RF systems - examples
- RF integrated circuits – examples
- Summary
- Assignment

Goals of the lecture

- **Orientation in the field of wireless communication**
  - Understanding trends, applications, challenges, directions
  - Getting overview of the landscape in wireless communications
    - Companies
    - Universities
    - Institutes
- **Getting familiar with RF systems**
- **Getting familiar with real RF integrated circuit designs**
- **Making the link between course content and examples of RF integrated circuits**

Scope

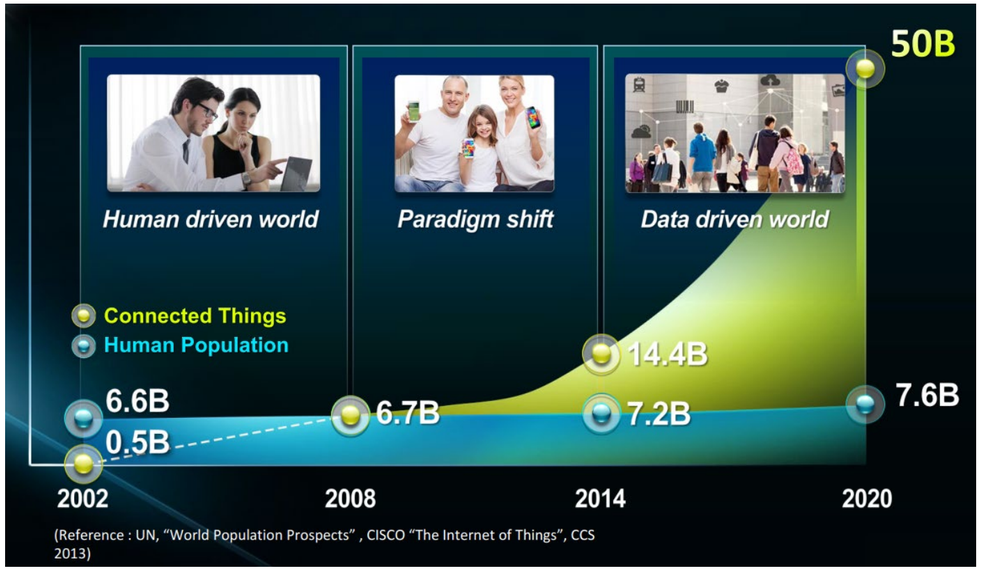


- Scope: TRX from application, system and circuit design perspective
- Purpose: signal conditioning
- Goal: minimizing impairments (noise, nonlinearity, energy)

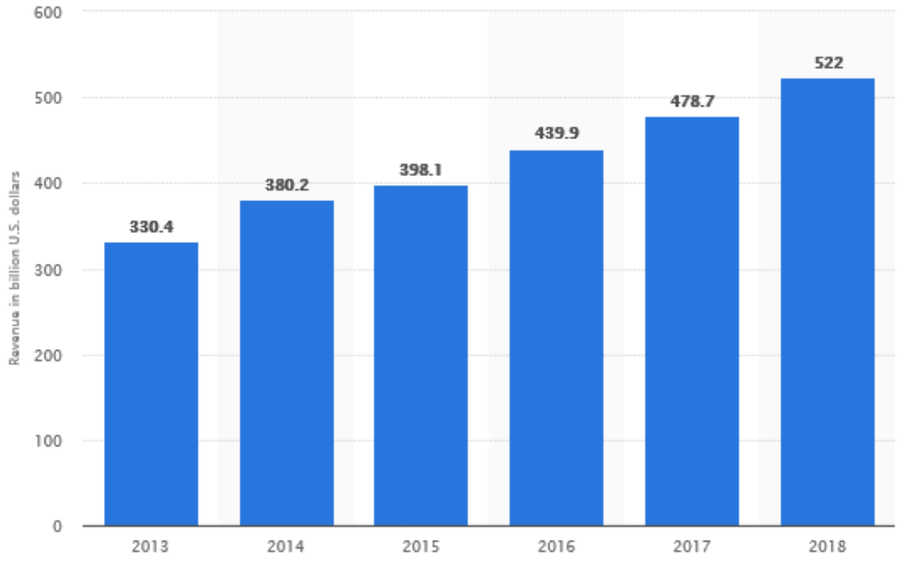
Development of Wireless Communications

- **Observations**
  - Wireless communications experienced explosive growth
  - Number of connected devices exponentially grows vs time
  - Smart phone revenue increases vs time

Connected devices vs population



Smart phone revenue



[SSCC Digest of Technical Papers, 2016, Plenary talk, Samsung Electonics]
[https://www.statista.com/statistics/237505/global-revenue-from-smartphones-since-2008/]

Applications for Wireless Technologies

Applications

Cellular & Connectivity

- 2G (GSM, GPRS, EDGE)
- 3G
- 4G
- 5G
- ZigBee
- Bluetooth
- WiFi, WiGig

Emerging applications

- 6G
- Automotive
  - radar
  - self & driving assistance
- Medical, BAN
  - monitoring
  - detection
- Industry
  - machine to machine com
  - identification
- Spectroscopy
- THz imaging
- Flexible electronics
- Environment & food monitoring
- Agriculture

Important !!!

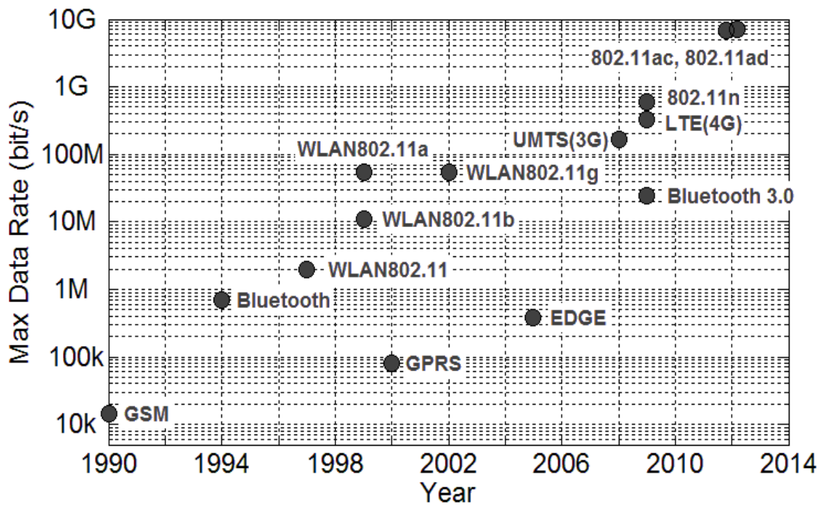
Trends in Wireless Technologies

Applications

Important !!!

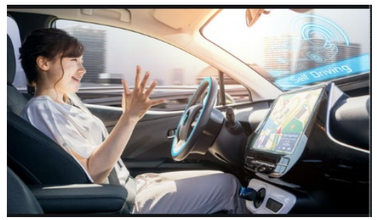
Cellular & Connectivity

- Phone centric
- Progress to higher data rates
- Drivers: commodity & low cost



Emerging applications

- Fast growing field
- Car and medical centric



- Extension to different areas
  - Environment
  - Food
  - Agriculture
- Drivers: quality & low cost

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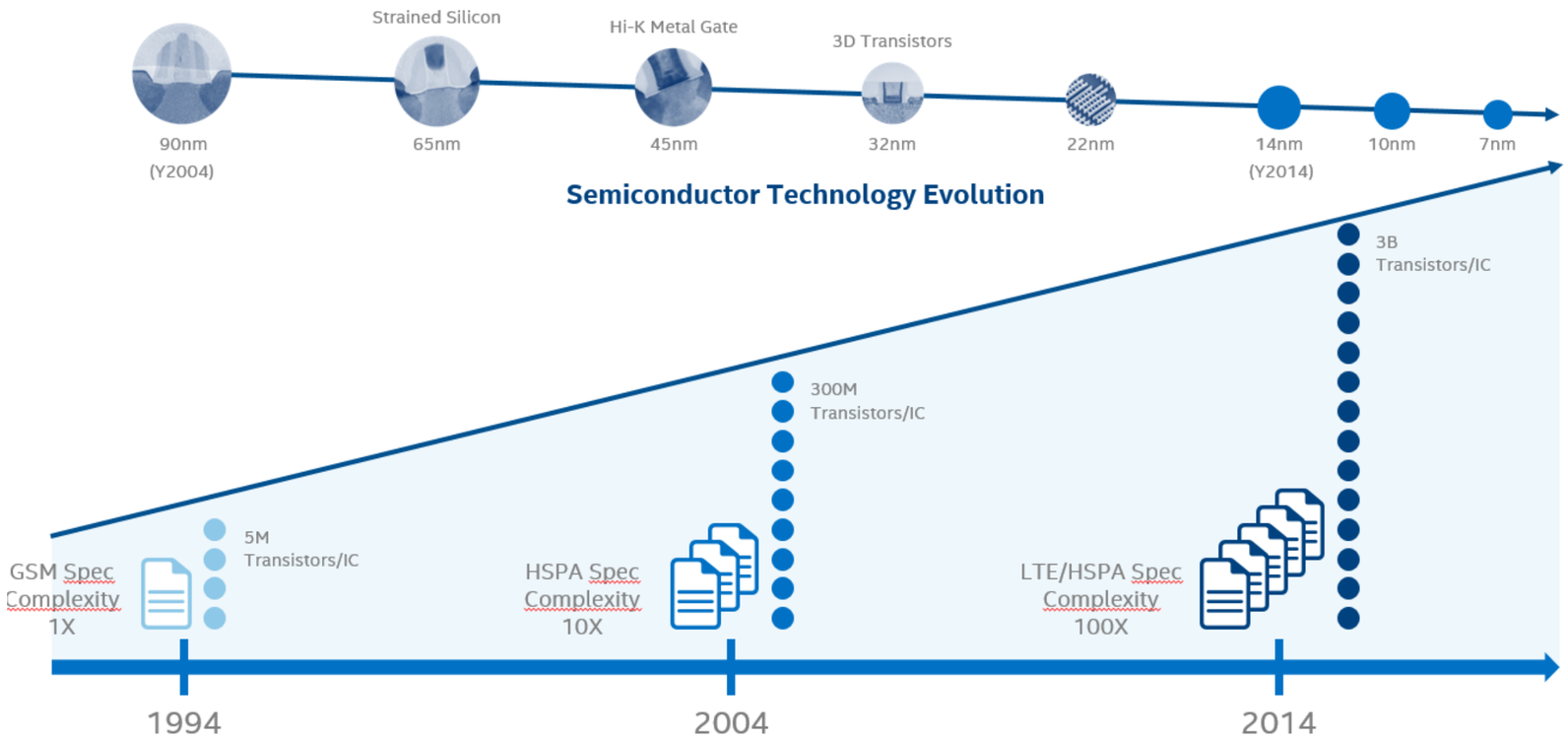
Trends in semiconductor technologies

CMOS

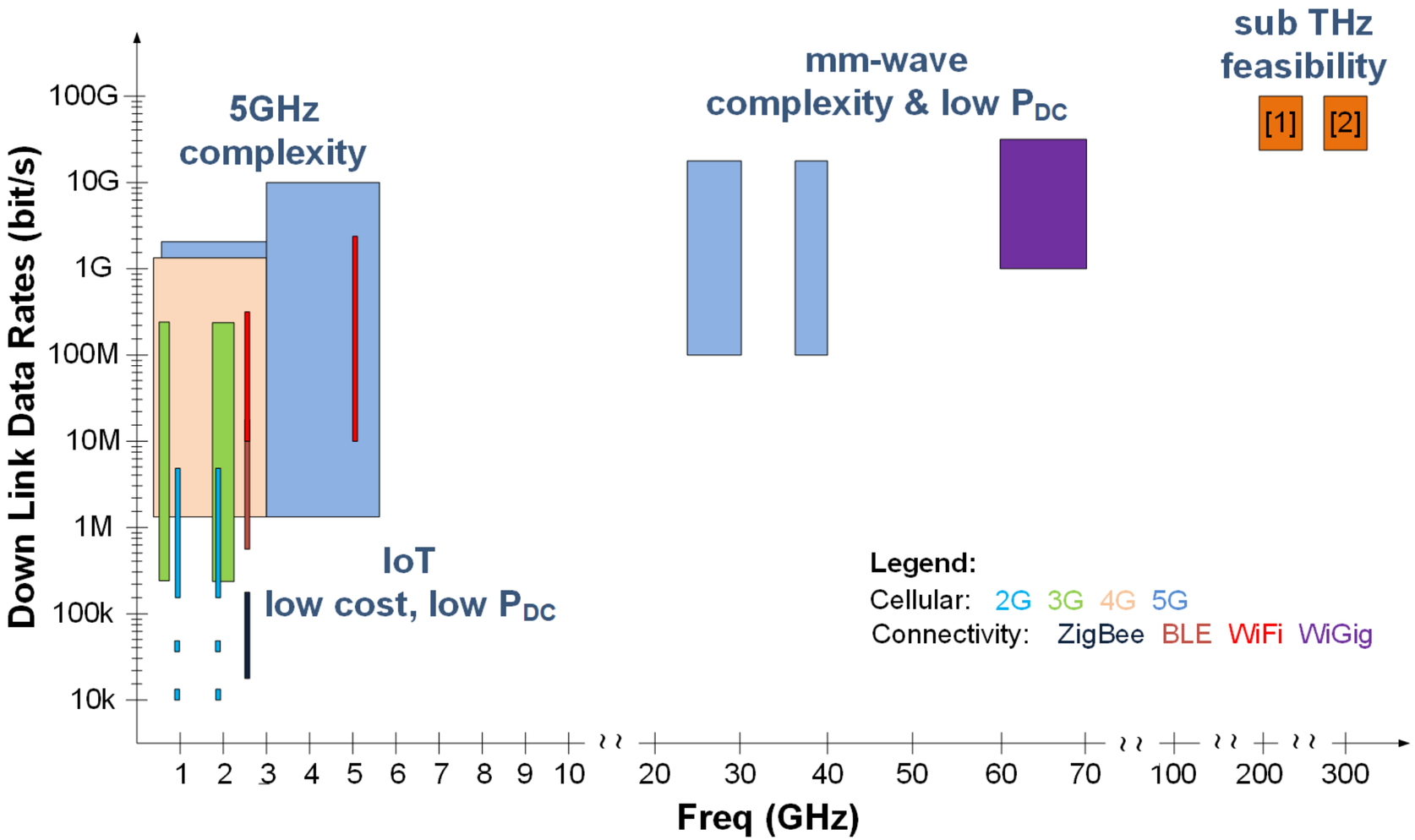


Important !!!

- Moore's law enabled modern wireless communications
- Supply voltages are decreasing
- World is waiting for alternative to CMOS !!!

[A. Keddy., `How to Achieve 1000x More Wireless Data Capacity? 5G?`, Evening Session, ISSCC, 2015]

Cellular & Connectivity Challenges



[1. R. Pfeiffer et al., `A 16-QAM 100-Gb/s 1-M Wireless Link With an EVM of 17% at 230 GHz in an SiGe Technology`, 2019]
[2. K. Okada et al., `A 42Gb/s 60GHz CMOS Transceiver for IEEE 802.11ay, 2016]

Challenges and Focus in Emerging Applications

- Combination application/system/circuit
- Multidisciplinary approach
- Proof of concept
- Form factor

- Example: sensing plant health status

https://vandijkseg.nl/en/plant-passport/pot-stick-labels/

- Form factor reduction in mobile communications

1982 2020

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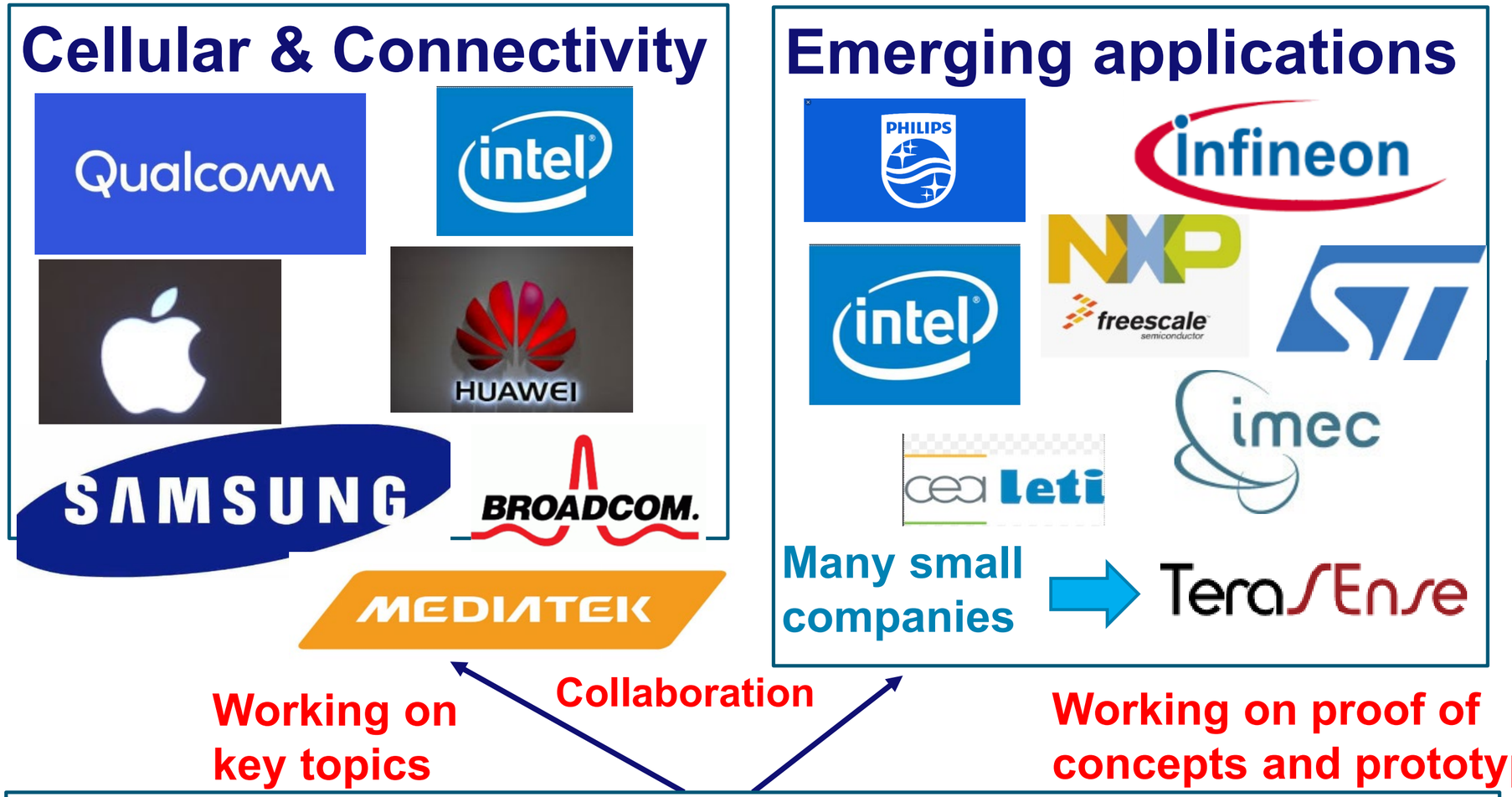
Wireless Communications Landscape

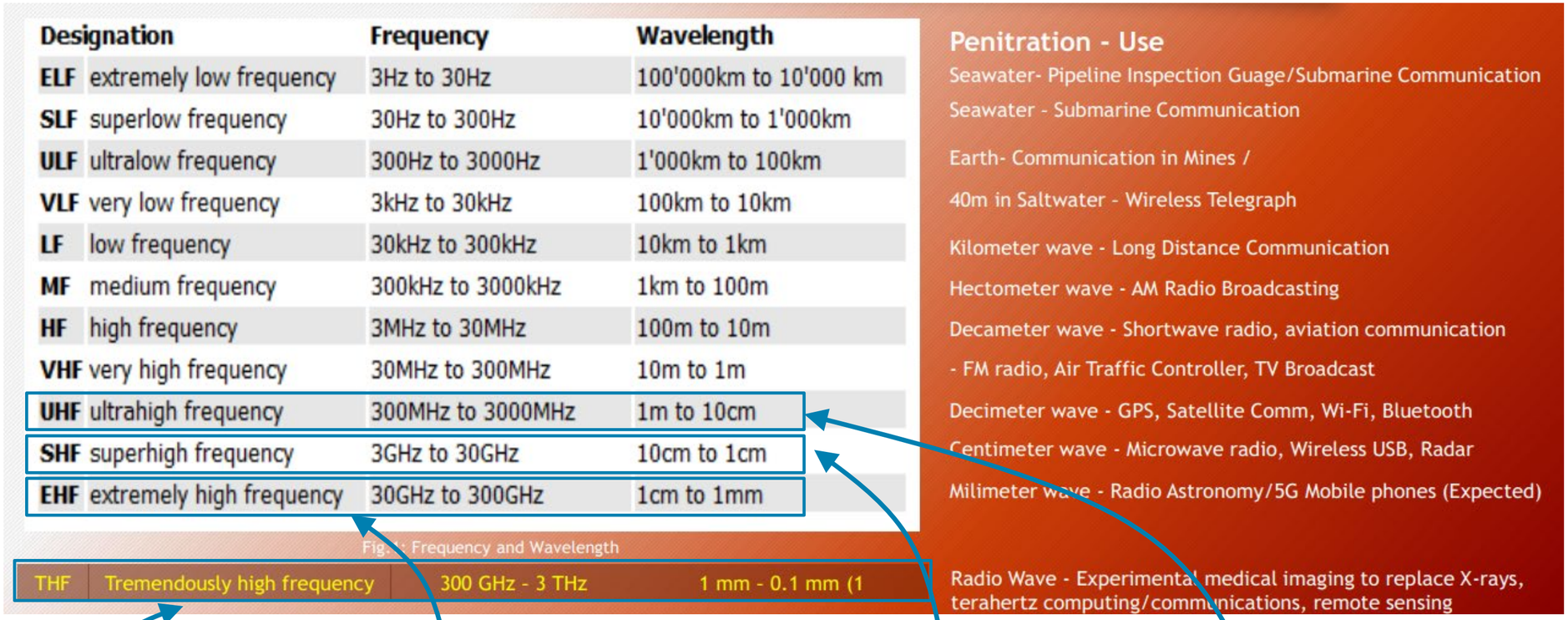


Engineer career - possibilities

- **Industry**
  - Properties: product oriented, focused on certain task, practical
  - Career ladders
    - Management: group lead, department lead, director, CEO
    - Technical: junior
- **Academia**
  - Properties: scientific oriented, broad scope, theoretical & practical
  - Career lather
    - Scientific: assistant professor, associate professor, full professor

Radio Frequency (RF) Spectrum

- RF spectrum for wireless communications is the same as high way for traffic
- Spectrum division and use



Designation		Frequency	Wavelength
ELF	extremely low frequency	3Hz to 30Hz	100'000km to 10'000 km
SLF	superlow frequency	30Hz to 300Hz	10'000km to 1'000km
ULF	ultralow frequency	300Hz to 3000Hz	1'000km to 100km
VLF	very low frequency	3kHz to 30kHz	100km to 10km
LF	low frequency	30kHz to 300kHz	10km to 1km
MF	medium frequency	300kHz to 3000kHz	1km to 100m
HF	high frequency	3MHz to 30MHz	100m to 10m
VHF	very high frequency	30MHz to 300MHz	10m to 1m
UHF	ultrahigh frequency	300MHz to 3000MHz	1m to 10cm
SHF	superhigh frequency	3GHz to 30GHz	10cm to 1cm
EHF	extremely high frequency	30GHz to 300GHz	1cm to 1mm

Fig. : Frequency and Wavelength

THF	Tremendously high frequency	300 GHz - 3 THz	1 mm - 0.1 mm (1

THZ

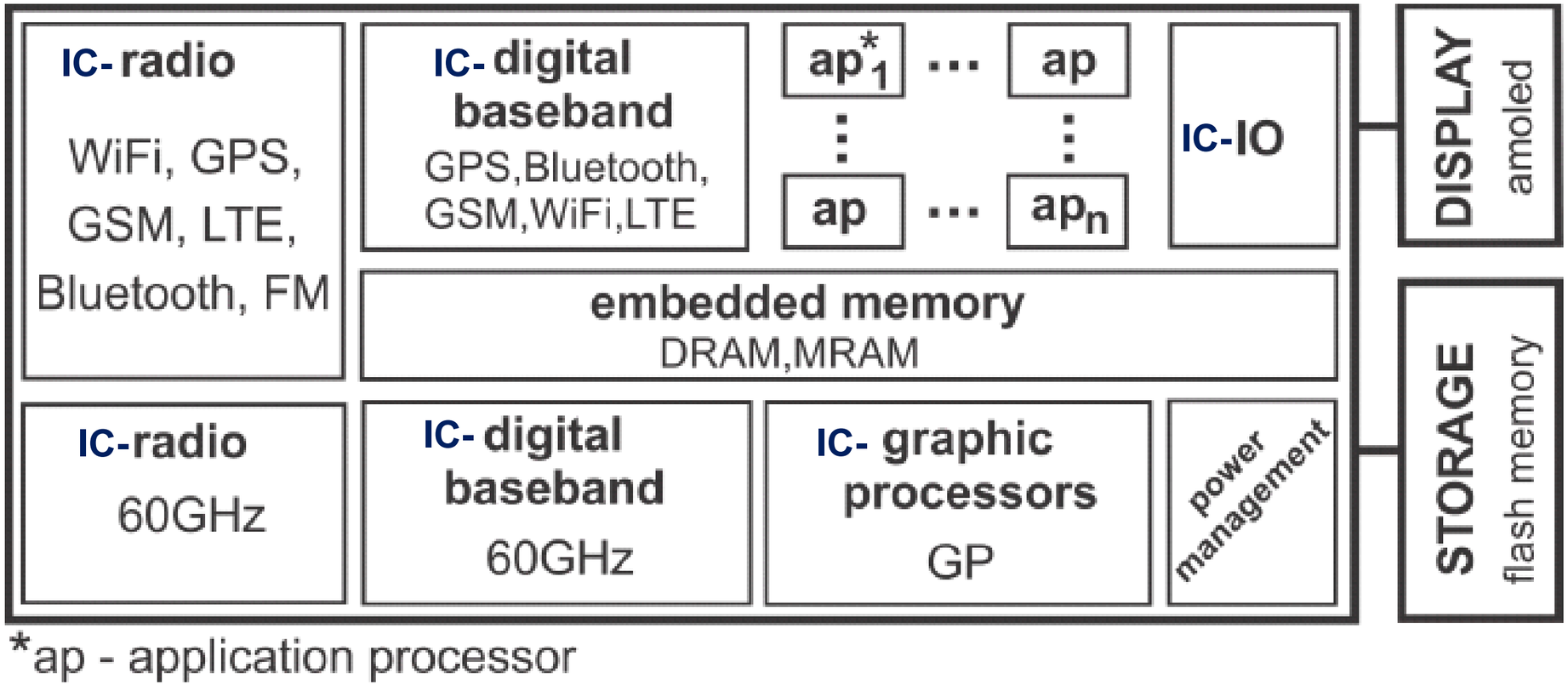
mm-wave

5G including mm-wave

IoT, 5G

[https://its-wiki.no/images/3/3f/Frequency_range_Zyyad.pdf, 2016]

Smartphone architecture

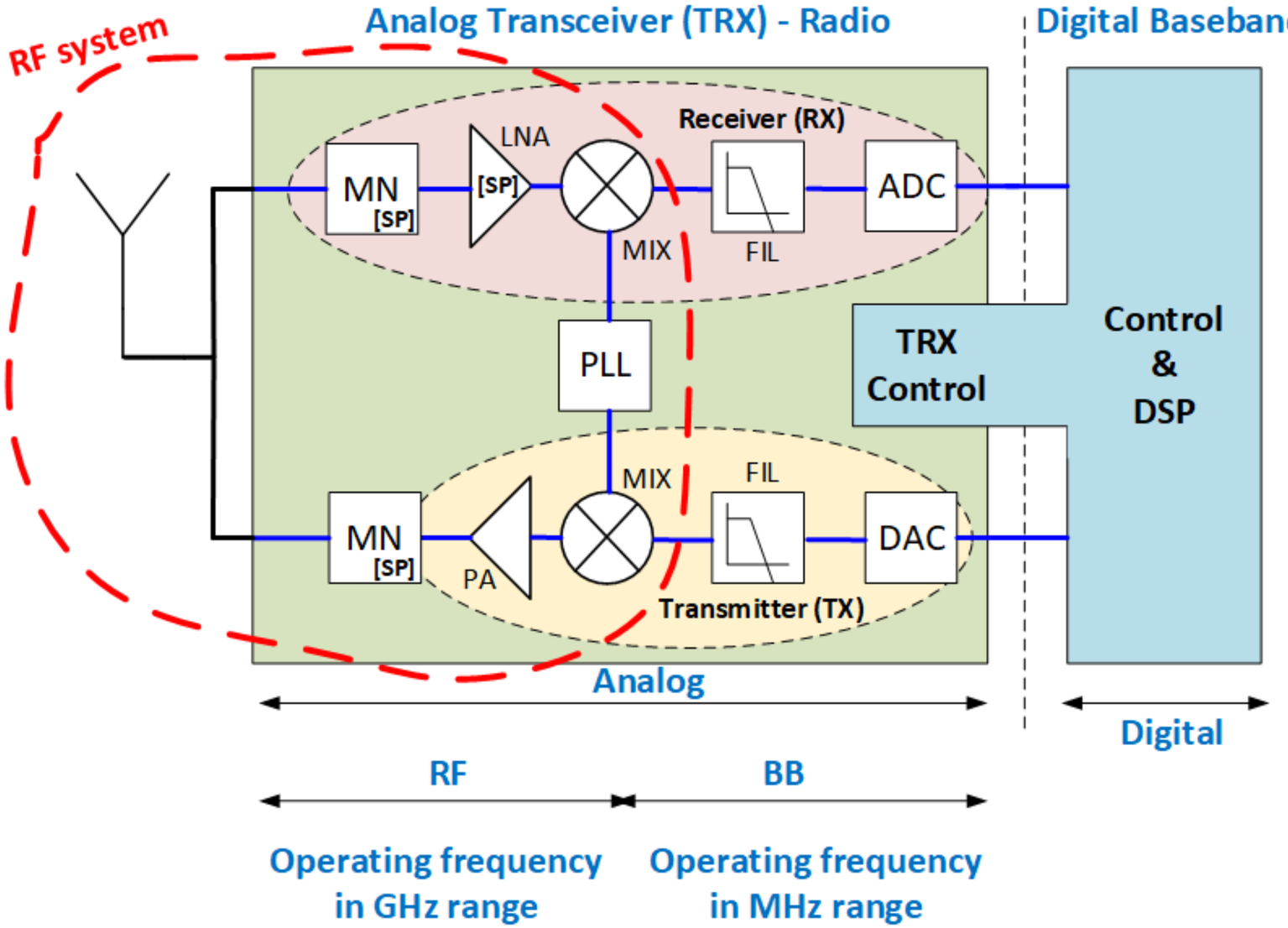


*ap - application processor

IC – integrated circuit (chip)

PCB – printed circuit board

RF system - transceiver block diagram



TRX functions **Important !!!**

Data conversion
Filtering/selectivity
Frequency conversion
Amplification
Frequency synthesis

Legend

RF – radio frequency
BB - baseband
MN – matching netwok
LNA – low noise amplifier
MIX – mixer
FIL – filter
PA – power amplifier
ADC – analog to digital converter
DAC – digital to analog converter
DSP – digital signal processing
PLL – phased locked loop

RF system example: DECT TRX

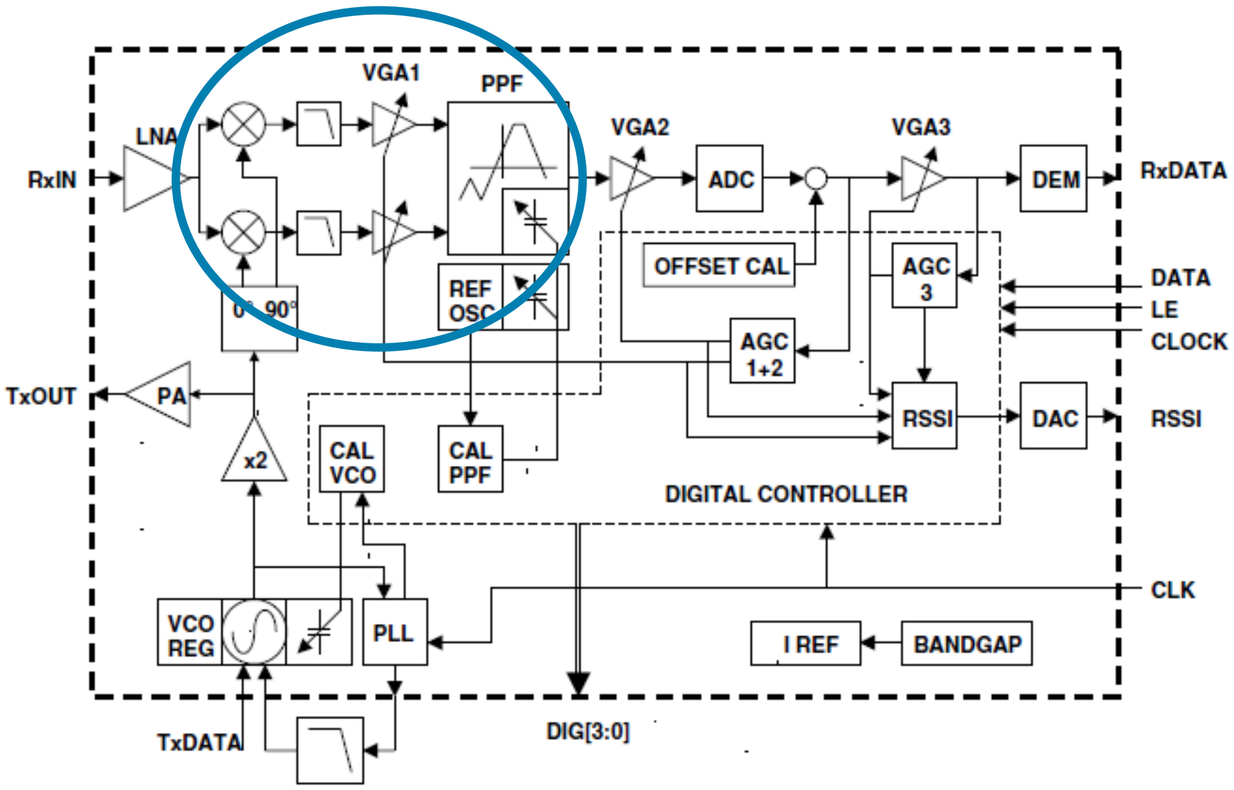


Figure 25.6.1: The transceiver block diagram.

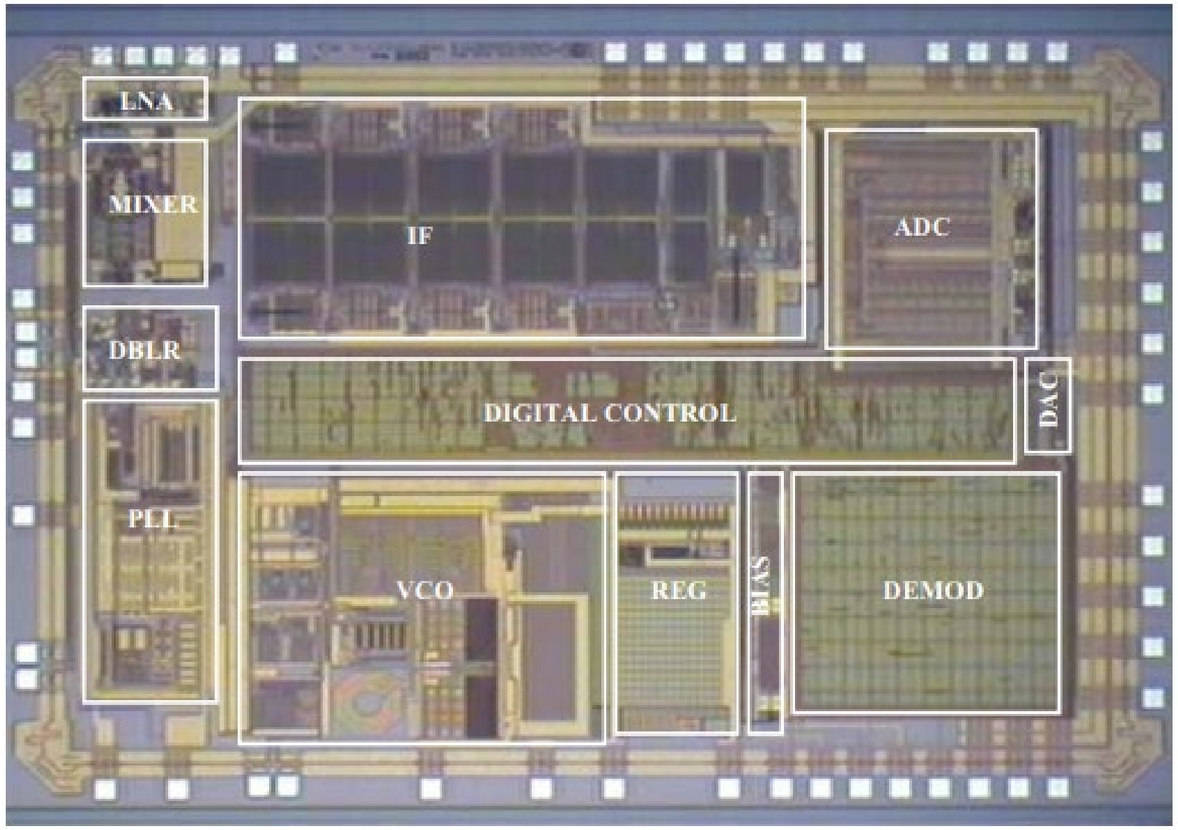


Figure 25.6.7: Die micrograph.

[A. Leeuwenburgh et al., ``A 1.9GHz Fully Integrated CMOS DECT Transceiver``, ISSC, 2003]

RF system example: 2G/3G/4G Transmitter

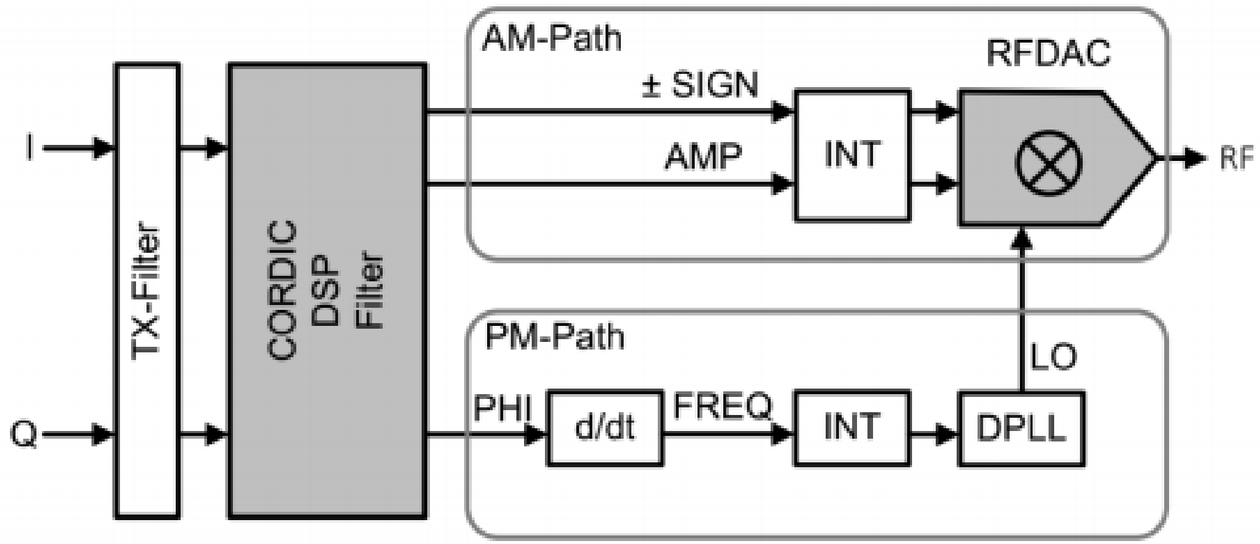


Figure 13.2.1: Concept of digital polar modulator with signed AM path.

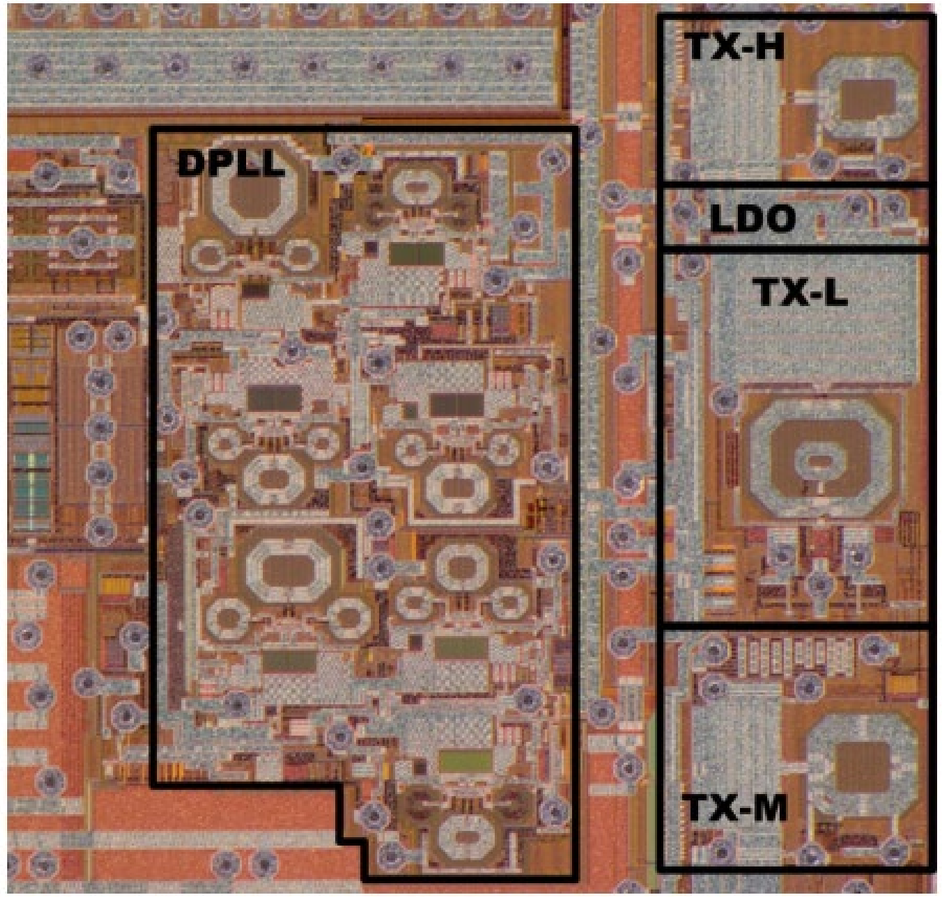
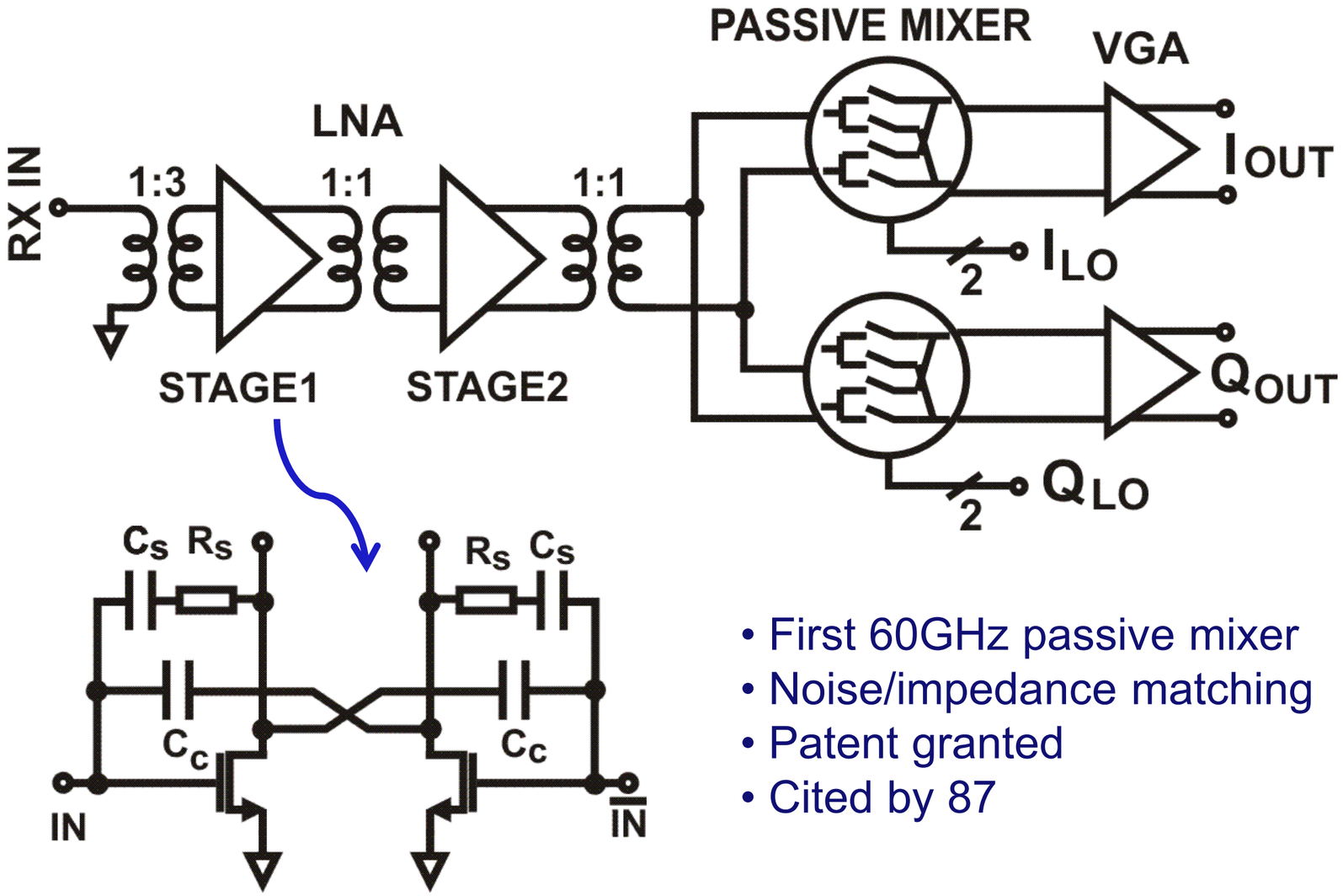
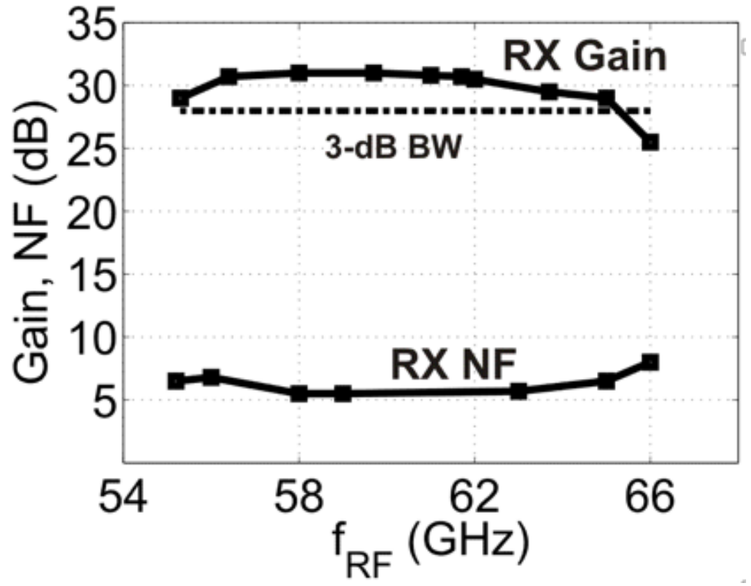


Figure 13.2.7: Die micrograph including DPLL and AM path of TX.

[M. Fulde et al., "A Digital Multimode Polar Transmitter Supporting 40MHz LTE Carrier Aggregation in 28nm CMOS", ISSCC, 2017]

RF system: 60GHz RX front-end





- First 60GHz passive mixer
- Noise/impedance matching
- Patent granted
- Cited by 87

ISSCC 2012

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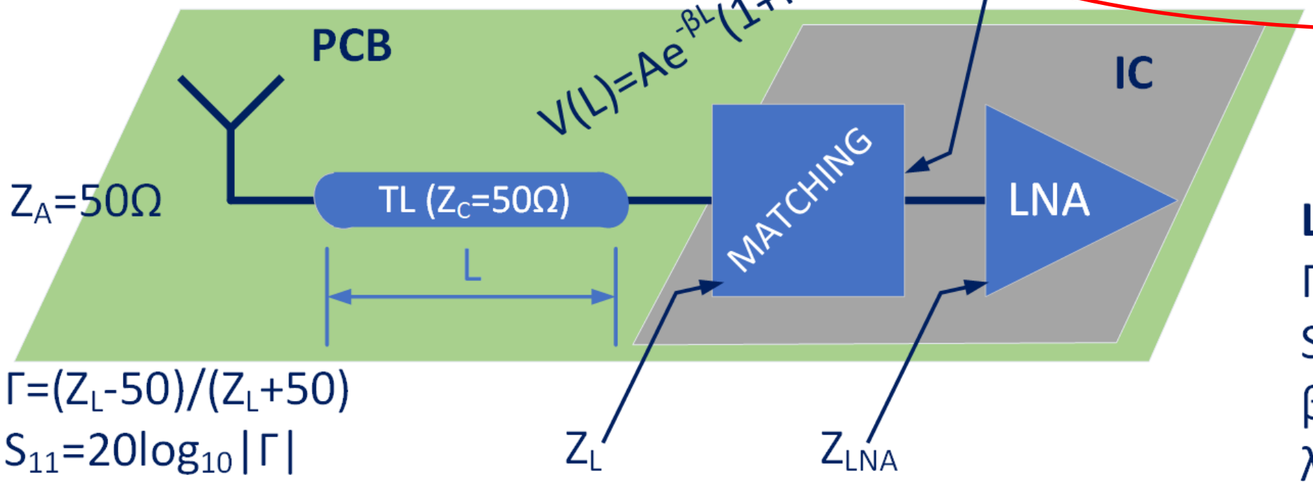
[V.Vidojkovic et al., "A low-power 57-to-66GHz transceiver in 40nm LP CMOS with −17dB EVM at 7Gb/s," ISSCC Dig. Tech. Papers, 2012]

60GHz LNA design and link to course topics

- LNA is challenging block with many requirements:
  - High gain
  - Stability
  - Impedance matching
    - In order to prevent reflections S_{11}< -10dB
  - Low noise figure

Topics addressed in course

$Z_S=Z^*_{LNA}$ -> Impedance match for best S_{11}
$Z_S=Z_{NM}$ -> Noise match for best NF



$\Gamma=(Z_L-50)/(Z_L+50)$
$S_{11}=20\log_{10}|\Gamma|$
$\beta=2\pi/\lambda$
$\lambda=c/f$

Legend
Γ – reflection coefficient
S_{11}- reflection coef. in dB
β – propagation constant
λ – wave length

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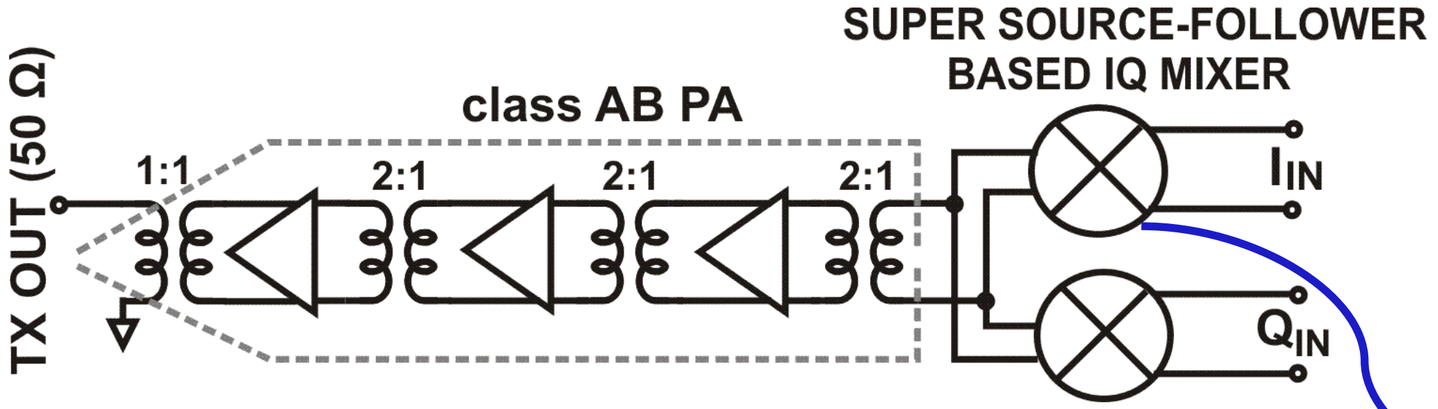
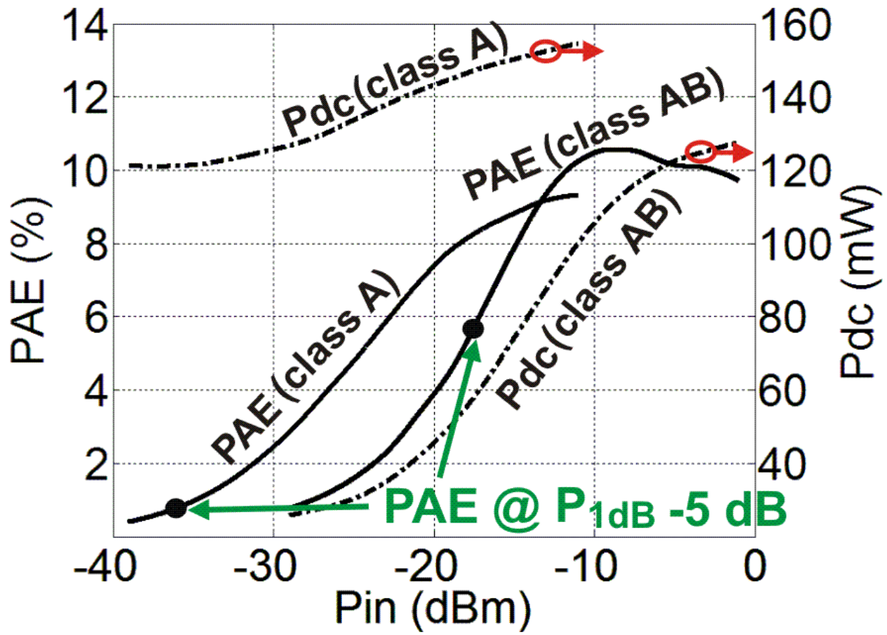
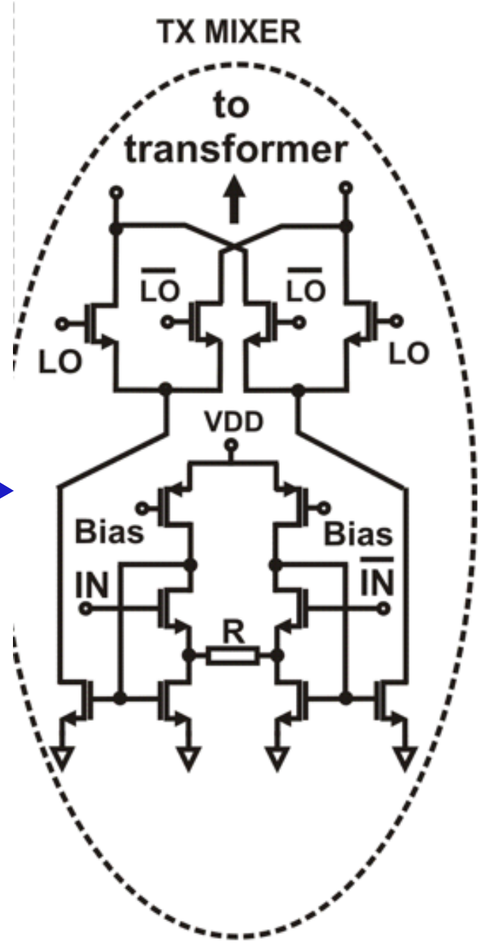
RF system and circuit example: 60GHz TX front-end



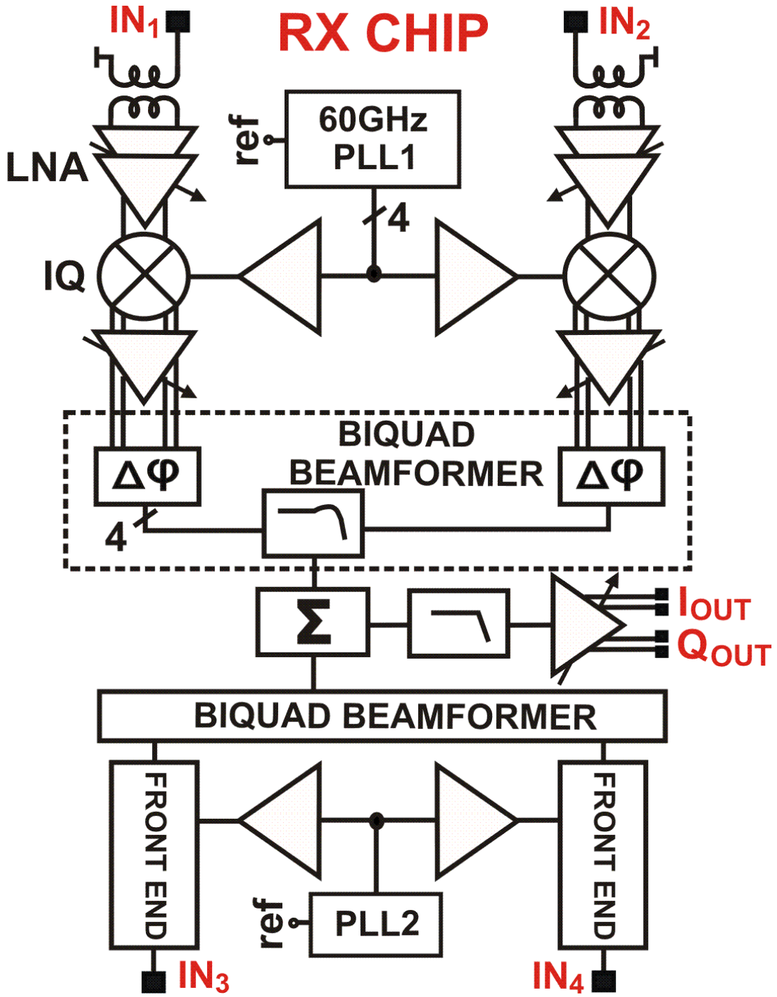


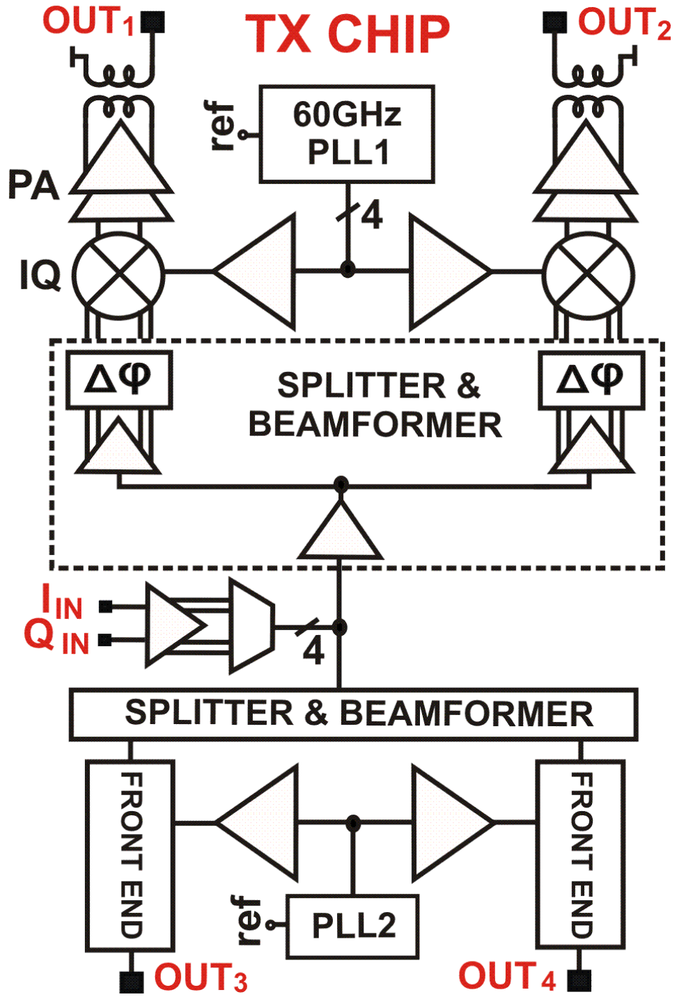


- First 60GHz class AB PA
- PAE of 5.7% at 5dB back-off
- Patent granted

[V.Vidojkovic et al., "A low-power 57-to-66GHz transceiver in 40nm LP CMOS with −17dB EVM at 7Gb/s," ISSCC Dig. Tech. Papers, 2012]

RF system example: 60GHz RX and TX chips





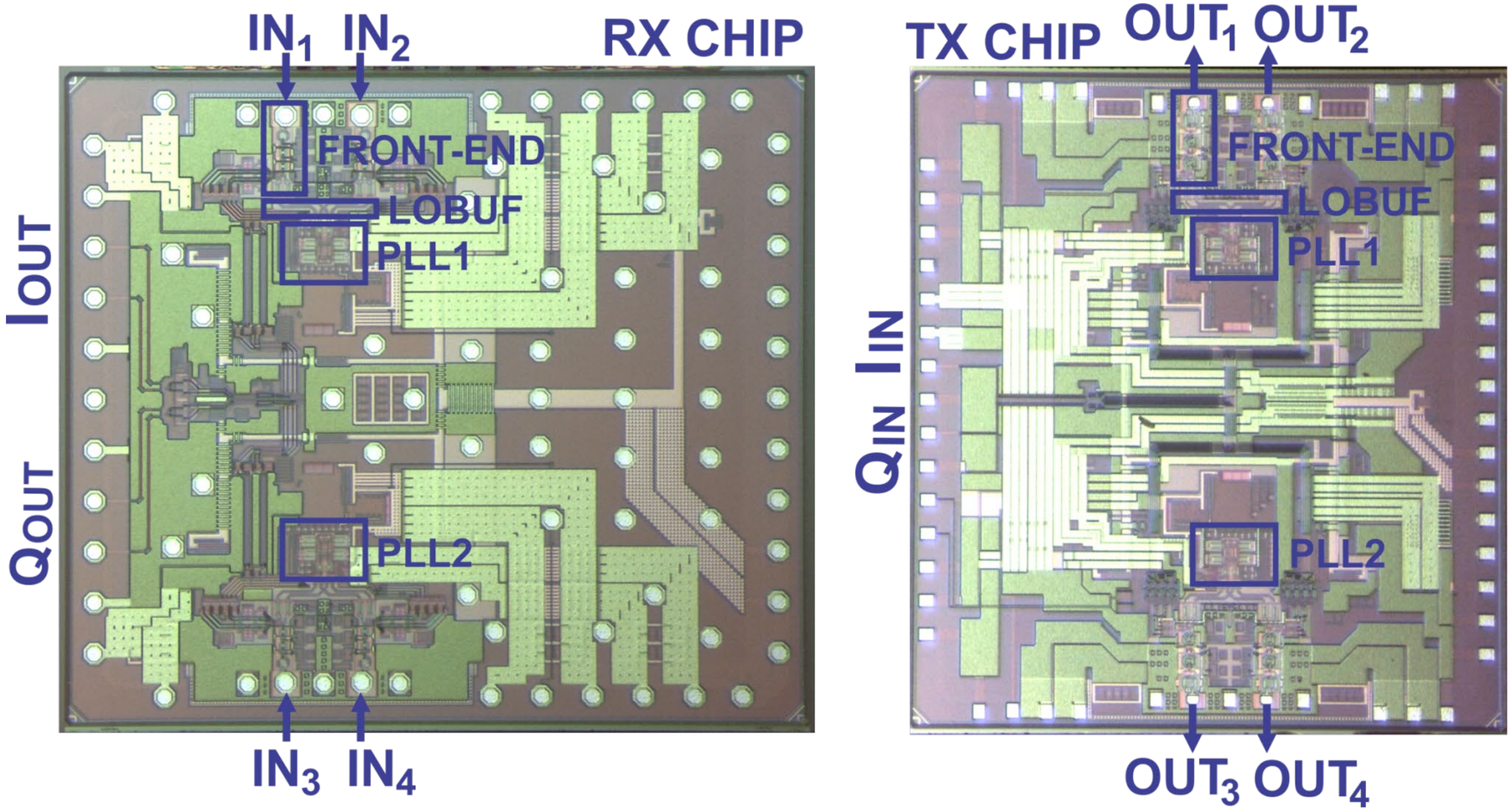
ISSCC 2012 — Institute of Electrical and Electronics Engineers — University of Pennsylvania

CICC Invited, 2013

TU/e Technische Universiteit Eindhoven University of Technology

[V. Vidojkovic et al., "A low-power radio chipset in 40nm LP CMOS with beamforming for 60GHz high-datarate wireless communication," ISSCC, 2013]

Die phots of 60GHz RX and TX chips



- Digital CMOS 40nm LP, 7 Cu layers + 1 Al layer, V_{DD} = 1.1V
- Occupied area: RX 6.5mm^2, TX 6mm^2

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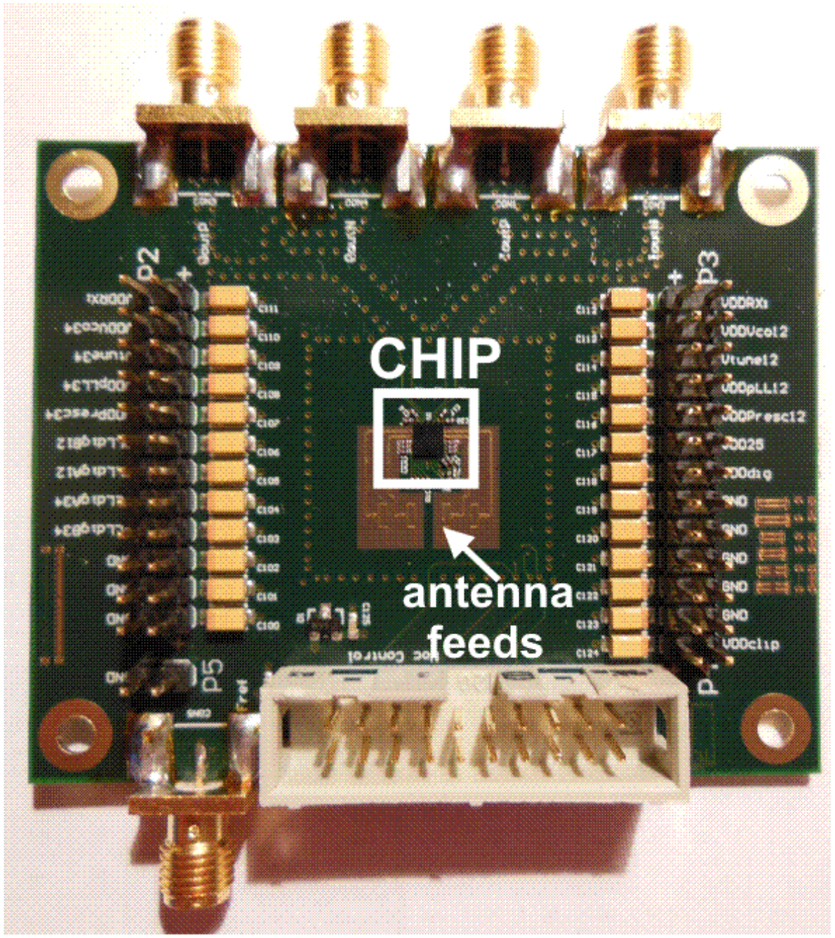
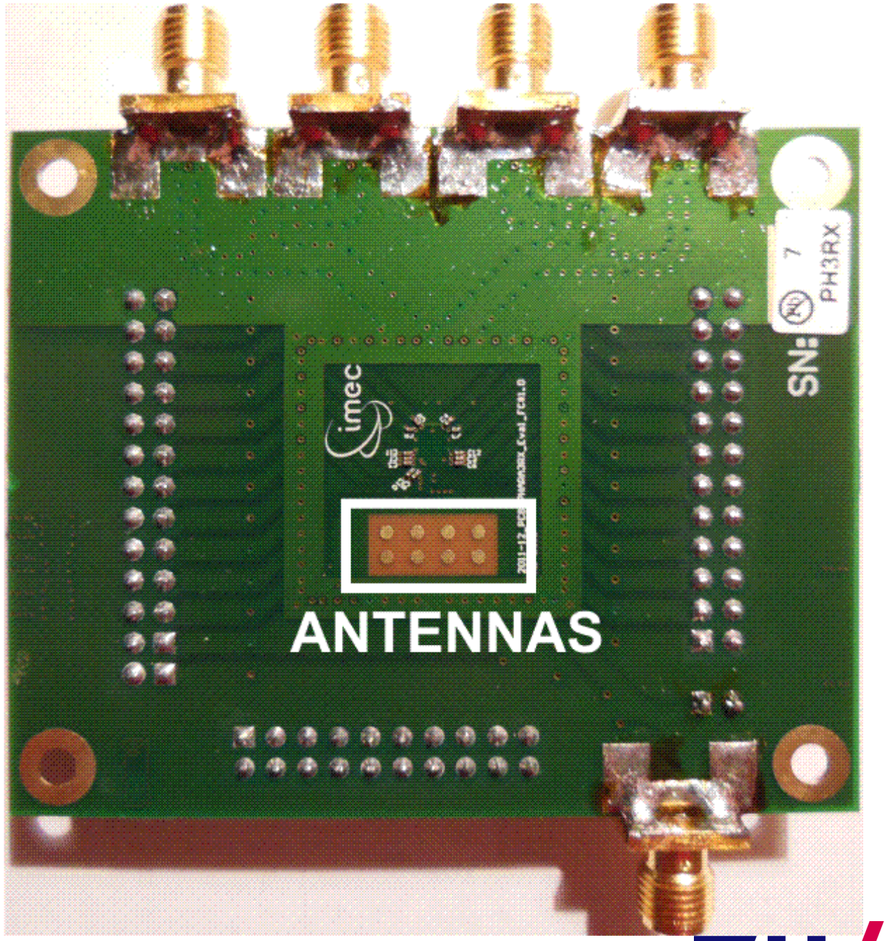
[V. Vidojkovic et al., "A low-power radio chipset in 40nm LP CMOS with beamforming for 60GHz high-datarate wireless communication," ISSCC, 2013]

60GHz RX module photo

FRONT-SIDE



BACK-SIDE



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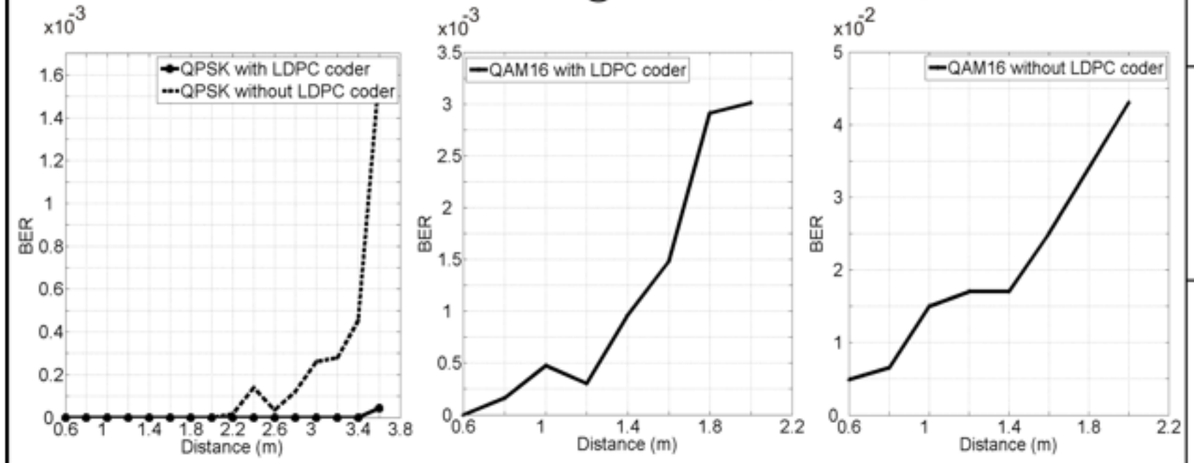
[V. Vidojkovic et al., "A low-power radio chipset in 40nm LP CMOS with beamforming for 60GHz high-datarate wireless communication," ISSCC, 2013]

Characterization of 60GHz TX-RX LINK

BER VS. RX-TX DISTANCE @ CH1 FOR QPSK AND QAM16

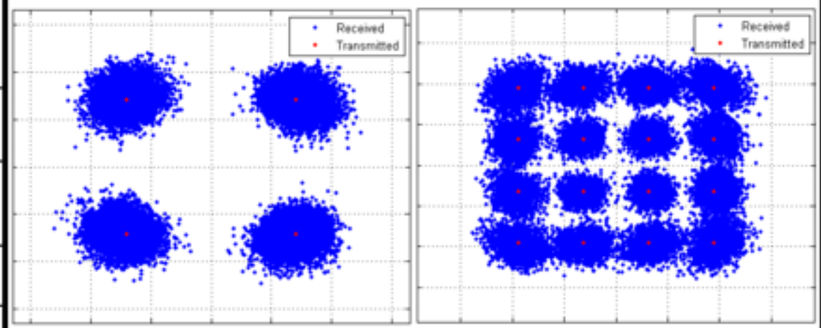


MOD	CHANNEL	EVM @ 60 cm distance	SNR @ 60 cm distance
QPSK	CH1	-14.8	15.5
	CH2	-14.8	16.7
	CH3	-14	14.9
QAM16	CH1	-15.2	16.3
	CH2	-15.2	16
	CH3	-14.2	15.1

RX and TX performance		
	RX	TX
IRR (dB)	25	
LO feedthrough	-68dBm	-20dBc
S11 between 57-66GHz (dB)	<-9	-10
ESD(HBM, kV)	4	7.7
ESD(CDM, kV)	1.1	2.6

LO performance PLL1&PLL2		
RANGE (GHz)	54.4 - 63.2	
CHANNEL	PN @ 1MHz (dBc)	INT. PN (dBc)
CH1	-89	-20.3
CH2	-85	-19.2
CH3	-85.6	-18.7
P_{DC}	263mW	

CONSTELLATIONS @ CH1 FOR QPSK AND QAM16
(32768 symbols)



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[V. Vidojkovic et al., "A low-power radio chipset in 40nm LP CMOS with beamforming for 60GHz high-datarate wireless communication," ISSCC, 2013]

Summary

- Relevance of wireless communications is increasing
- Applications in wireless communications are increasing
  - The last 20 years were about communications
  - The race towards high data rates will continue
  - Nowdays medical and automotive applications are in the focus
  - **There is plenty of work in front of us**
- Digitization of the world is progressing. But our world is analog and there will always be a need for an analog interface to digital world
- The course content is very practical and will help you in practice
- Provided RF system and RF circuit examples show relevance of course content